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Spectrophotometric monitoring of high luminosity active galactic nuclei – II. First results

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Summary. We report the first results obtained from a continuing programme of spectrophotometric monitoring of high luminosity active galactic nuclei (AGN). Analysis shows that significant emission line variations take place in high luminosity, high redshift objects. These variations occur on time-scales much shorter than those expected from photo-ionization models. These shorter time-scales can be explained if the optical and ultraviolet continuum is beamed towards the observer, leading to an anisotropic BLR and a selection effect in favour of cases in which the axis of this anisotropy is close to the line-of-sight.

1 Introduction

In Paper I (Pérez, Penston & Moles 1988b) of this series, we justified the need for a monitoring programme to study the spectrophotometric variations of high luminosity active galactic nuclei (HLAGN), stimulated by the results for lower luminosity AGN which have been obtained during the past decade. We have seen that although a majority of HLAGN have been known to be photometrically variable for more than two decades, no emission line variability has been reported until very recently for these objects. Burbidge & Burbidge (1966) reported variations of Mg II $\lambda 2800$ in 3C345 but these were disclaimed soon after, as photographic recordings were considered unreliable for this purpose. For the same object, Netzer *et al.* (1979) concluded that any Mg II flux changes were within observational uncertainties (20 per cent) in their study.

It has only been since 1986 that reports of emission line variability for individual high luminosity objects ($M_{\rm abs} < -23$) are to be found in the literature. From the ground, short time-scale (of the order of one to a few months) line variations have been claimed in C III] $\lambda 1909$ in 3C446 (Stephens & Miller 1984; unfortunately these data have not yet been published in a refereed journal). In a search for long-term variations, Zheng & Burbidge (1986) report the disappearance of Hβ in Pks 0736 + 017. Zheng *et al.* (1987) and Zheng (1988) also report Balmer emission line variability for other objects on a time-scale of years. From *International Ultraviolet Explorer (IUE)* data, very short time-scale changes have been reported for Lα in 3C232 (Bruhweiler, Kafatos & Sofia 1986; but this seems to be due to an error in the extraction of the spectrum, O'Brien, Gondhalekar & Wilson 1988), the same line in 3C446 (Bregman *et al.* 1986) and this and other lines in other objects (Gondhalekar *et al.* 1987).

In the present article we show how emission line variability in HLAGN may be a common feature of these objects and we describe some of the variations observed in the line profiles. These variations occur on a shorter time-scale than predicted by the standard photo-ionization models (see Introduction in Paper I). Section 2 presents the results for the individual objects. In Section 3 we comment on the possible scenarios suggested by the data and suggest an explanation of the rapid line variations, while in Section 4 we suggest how to improve the programme and what future developments may be expected.

2 Results for individual objects

In this section we present and comment on the variability in the data on individual objects.

2.1 Pks 2134 + 004

A first glance at fig. 2(b) of Paper I shows that this object has varied during the period over which we have observed it. The variability is most apparent at the last epoch, when the continuum is brighter than at the other three, between which the continuum did not vary significantly. In this latter spectrum, changes also clearly occur in the emission lines, which are also distinctly brighter than at previous epochs.

Table 1. Fluxes and equivalent widths of emission lines in Pks 2134 + 004. Line fluxes are in units of 10^{-14} erg cm^{-2} s^{-1} and continuum flux is in units of 10^{-17} erg cm^{-2} s^{-1} Å^{-1}.

	4.8.84	**13.6.85**	**6.6.86**	**30.7.86**	**W84**[a]	**RS80**[b]
Lα+NV	19.6/499	21.4/297	17.3/290	25.9/236		62.4/270
NV				1.82/		
blend 1400Å	2.0/43.4	2.1/38.0	2.1/38.8	2.6/27.9		
CIV	4.0/89.2	5.6/102	5.0/96.2	7.2/74.6	6.1/104	7.1/56
blend 1640Å	2.9/75.6	2.2/46.9	2.2/48.9			
CIII]	3.9/125	3.2/75.7	2.4/61.5	4.4/62.8		2.2/29
cont. 1700Å	38.9	49.2	46.4	73.9		

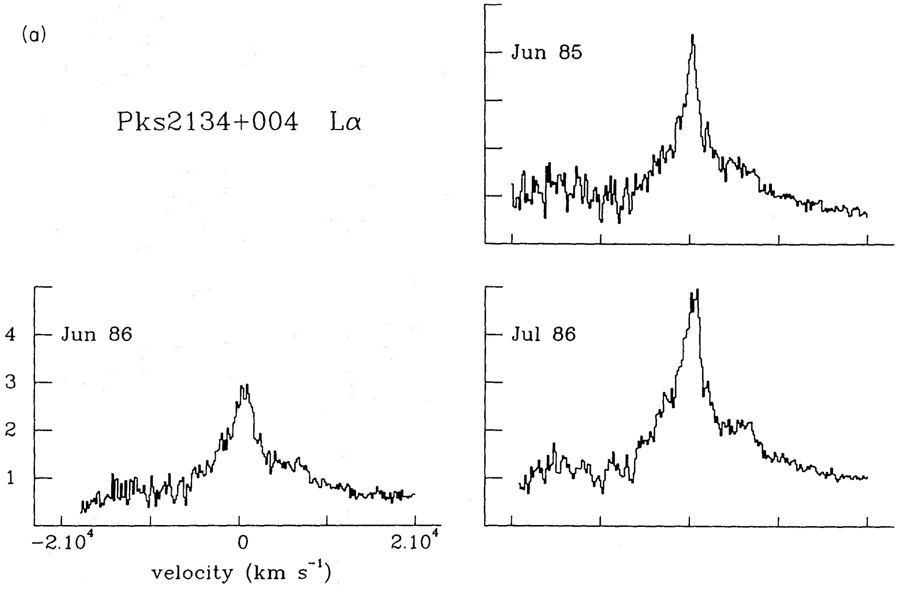
[a] Wampler *et al.* (1984).
[b] Richstone & Schmidt (1980).

The variation observed between the last two epochs, 1986 June to July, seems to imply that the BLR in this object is very small, because the continuum has changed by 46 per cent (*cf.* Table 1) and the lines have followed this variation by brightening by about the same fraction (40 per cent for Lα, 36 per cent for C IV and 59 per cent for C III]). The interesting point about this is that the change has happened in less than two months (from June 6 to July 30), indicating, for an isotropic BLR, that a large fraction of the emitting gas is located within two light months of the continuum source. Possible explanations for this apparent small size are discussed in Section 3.

2.1.1 Line profiles

Fig. 1(a) and (b) presents the Lα and C IV profiles, respectively, plotted on the same velocity scale for all the epochs. The profiles of these two emission lines (which show the same variability from epoch to epoch) are very similar, except for the core of Lα which appears peakier (*cf.* fig. 2 of Paper I; this might be due to a contaminating effect by an intervening Mg II λ2800 absorption system at $z = 0.6292$ clearly visible just redward of the C IV peak).

A clear change, which occurred between 1985 June and 1986 June (Fig. 2), is that the peak of Lα disappeared, the base of the core component also became narrower and the rest of the line remained much the same in shape and luminosity. In 1986 July the line, although much



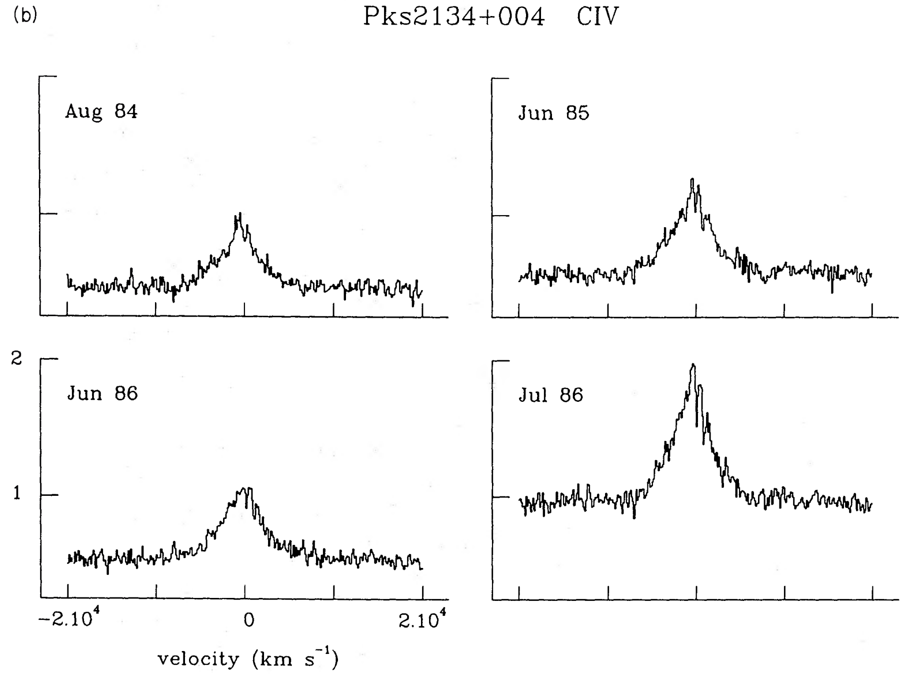


Figure 1. (a) Lα and (b) C IV profiles in Pks 2134+004. In each part, all the plots are in the same scale. The Lα data from 1984 August has not been used as it is too near the edge of the observed spectral range to allow reliable calibration.

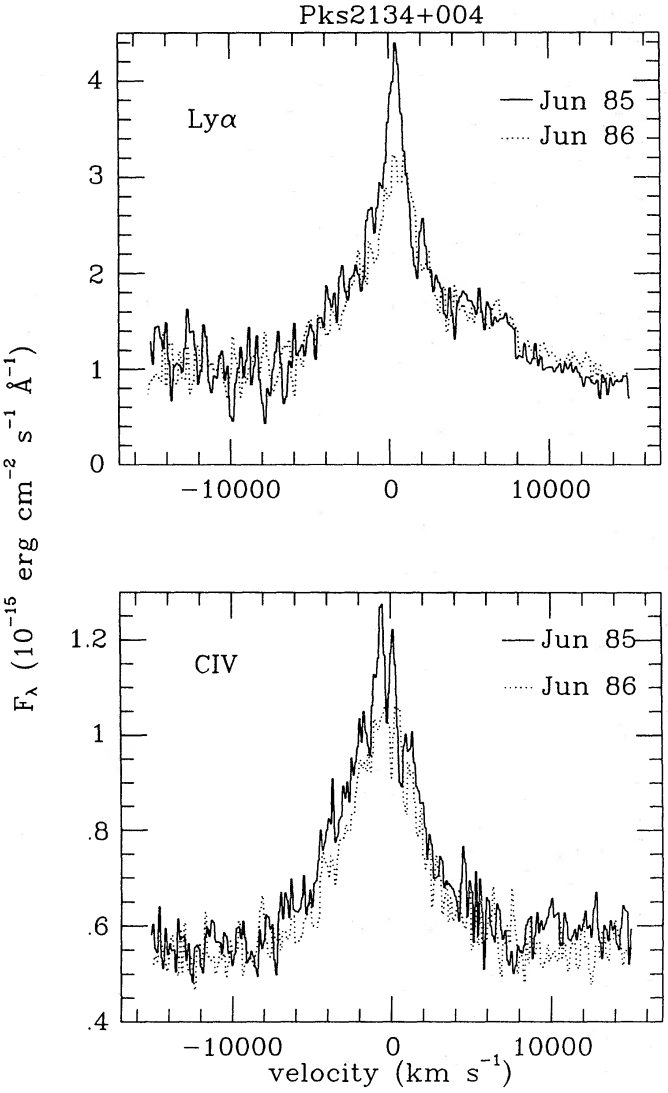


Figure 2. Comparison of the variations seen in Lα and C IV from 1985 June to 1986 June. The observed wavelength used as reference for the origin of velocities is 3570 Å for Lα and 4555 Å for C IV. The Lα data for 1986 June has been shifted upwards by adding a constant of three ordinate units to account for the continuum change. Note how the variations are more prominent in the line core (particularly for Lα).

brighter, still lacks the peak. The changes in C IV are similar to those in Lα. This line is also less peaked in 1986 June than in 1985.

There seem to be two different types of variation observed in the emission lines. The first, which would account for the gross flux changes, may reflect the overall response of the emitting material to changes in the ionizing source as indicated by the 1986 changes. The second, which explains the changes in the profile of the lines, could be due to variable self-absorption at low velocities. The latter might explain changes in the core of the lines. A careful check shows that the variable core structures are not caused by extended emission or differences in spectral resolution.

Another variable feature in the spectrum is the dip between the C IV and the 1640 Å blend. This is best seen in the 1985 June spectrum and its absence in other epochs is likely to be due to the presence of a very broad shallow C IV component, which is also seen in Lα, extending out to about $10–15\times10^3$ km s^{-1}.

2.1.2 Comparison with previous data

The literature was searched for previously published spectra of 2134 + 004 but there are only two references to emission line fluxes, by Richstone & Schmidt (1980) and Wampler *et al.* (1984), which are included in Table 1.

Visual inspection of an unpublished 2 Å pixel^{-1} AAT spectrum from 1976 August 18 (Fosbury, Penston, Ward & Wilson, private communication) shows very interesting features. The continuum is somewhat steeper and the emission lines are brighter. The C iv broad shallow component referred to above was much brighter, with the flux of this component (including the redward shelf) larger than the main C iv component. In 1976 the 1640 Å blend presented a lot of structure; in particular He ii λ1640 and O iii] λ1665, which are not resolved in our data, show up very distinctly, as well as an emission feature identified with [Ne iv] λ1601. The C iii] line is more clearly asymmetric to the blue. Also present in the 1976 spectrum is a broad blend between 2040 and 2240 Å which may be tentatively identified with He ii, N ii] and Fe ii emission and whose total flux is comparable to that of C iii] λ1909.

2.2 3C446

3C446 shows very interesting variations in its spectrum. The first change which we note is the difference in the profile of C iii] from the first (bottom) to the second spectrum (1984 August 1 to 4; *cf.* fig. 3b of Paper I). The core of the line is much stronger in the first spectrum. Although the effective resolution is different in both spectra (2.5 and 7.1 Å, respectively) it is not possible to reproduce the shape of the second C iii] line by degrading the resolution of the first spectrum. C iv also looks different between these epochs. In Fig. 3 the change in the profile of the C iv line looks, if anything, opposite to that in C iii], in that the spectrum taken on August 4 looks more core dominated while the flux in that of August 1 is spread more into the wings. The change in the total flux of the line is not significant in C iv (10 per cent in flux and 4 per cent in equivalent width; *cf.* Table 2), while it might be in C iii] (40 per cent in flux and 35 per cent in equivalent width); although the measuring error is larger for the latter, the fact that

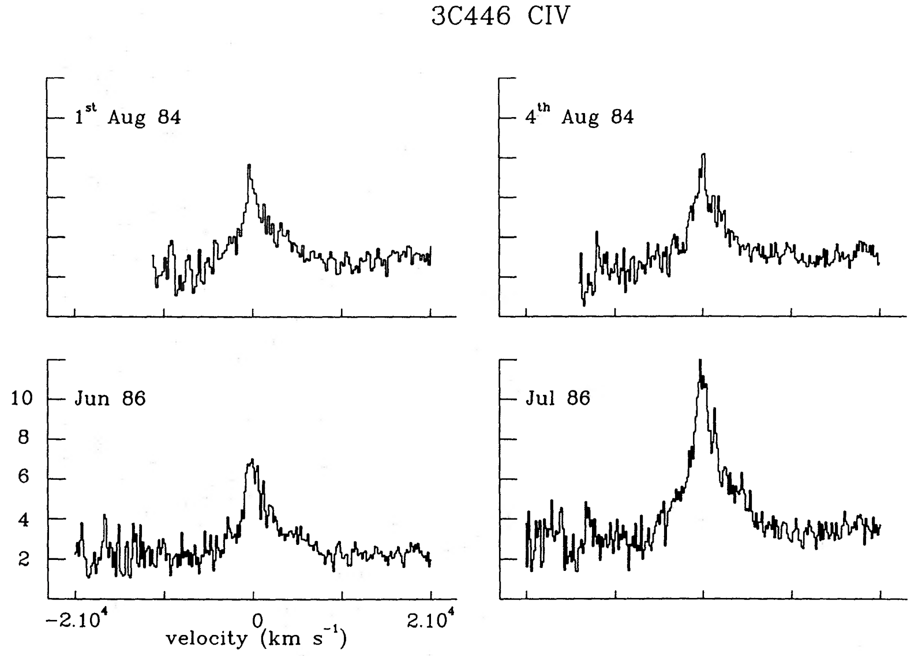


Figure 3. As in Fig. 1(b) but for 3C446.

Table 2. Fluxes and equivalent widths of emission lines in 3C446. Line fluxes are in units of 10^{-15} erg cm^{-2} s^{-1}. Measuring intervals for main lines are: 1500 < C IV < 1600 Å, 1845 < C III] < 1975 Å, 2755 < Mg II < 2845 Å.

	average	**1.8.84**	**4.8.84**	**5.6.86**	**30.7.86**	**31.7.86**
CIV	12.9/52.5	11.8/51.4	13.0/53.6	12.4/66.1	22.3/86.2	
blend λ1650	2.0/ 7.8					
NIII] λ1751	0.7/ 2.8					
? λ1815	0.3/ 1.1					
CIII]	3.9/16.1	6.2/22.1	4.2/15.7	3.0/16.9	6.6/28.6	4.7/21.9
blend λ2120	2.5/11.0					
MgII	3.2/12.6					

the change in flux is fully reflected in the equivalent width is telling us that it cannot be a flux calibration error. These three facts suggest that the changes might be real.

If there is extended line emission in the object, it is possible to mimic the effect of rapid variability by placing the slit in a slightly different position; however, we find no sign of extended emission in our data. In this regard (and assuming a relationship between the optical and radio morphologies), Simon, Johnston & Spencer (1985) find that the VLA and VLBI maps show a core-halo morphology, but all the structure seems to be confined to within 0.3 arcsec of the core component, so that this would not produce any significant effect in the spectrum due to a different positioning of the slit. On the other hand, the MERLIN map shown by Browne *et al.* (1982) shows some extended (less than 2 arcsec) radio structure at p.a. − 30°; as the p.a. for our 1984 observations was 0°, then significant C III] (but not C IV!) emission associated with this extended structure might conceivably account for the variations seen, given the different slit widths and seeing conditions between August 1 and 4. We therefore have some reservations about the physical reality of this extremely rapid variation.

Another change, as unexpected as the one just described, happened during the seven weeks that elapsed between the last two spectra, on 1986 June 5 and July 30. The object brightened

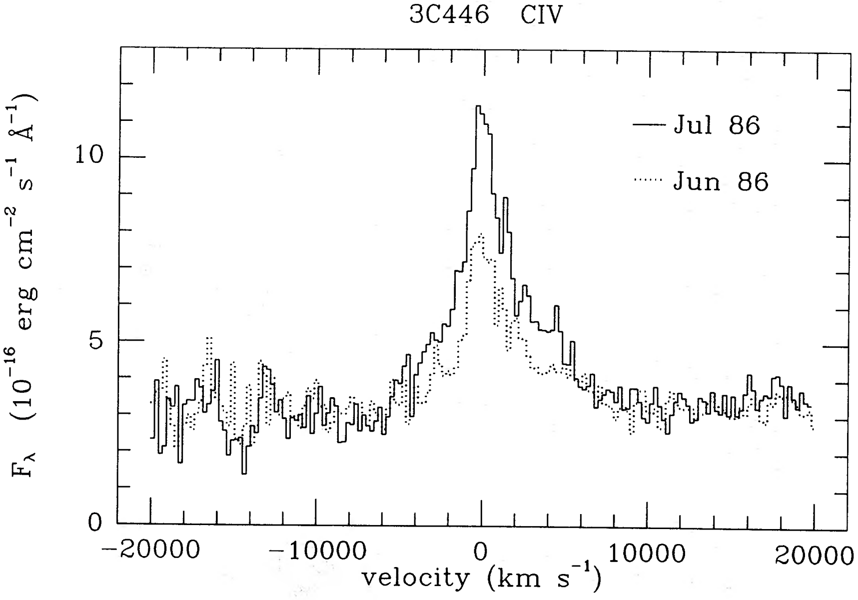


Figure 4. Comparison of the C IV profiles in 3C446 during 1986 June and July. Data have been binned up to 3 Å pixel^{-1}. The observed wavelength used as reference for the origin of velocities is 3726 Å. The June data have been shifted upwards by adding a constant of one ordinate unit to account for the continuum change. Note the dramatic change in line flux and profile.

in the continuum as well as the lines, C IV changing by 57 per cent in flux (26 per cent in ew) and C III] by 88 per cent in flux (49 per cent ew). The profiles of the lines are also different. This can be better appreciated in Figs 3 and 4. The C IV line presents two distinct components (core and wings) in both epochs, but while in June only the red wing was visible, by July this red wing had become fainter with respect to the core component and a blue wing appeared, also brighter than the red. In the profiles from 1984 the two component structure in C IV is not so clear. The 1986 change, which occurred in less than two months, is so clear that there is no doubt about its reality. Note that, while the largest change in C III] occurred between these two dates, for C IV it took place over the longer interval between 1984 August and 1986 July 30.

2.2.1 Comparison with previous data

In spite of the attention paid to 3C446, the non-uniformity of the data acquisition and gaps in the monitoring at different wavebands, make it difficult to put tight constraints on the various time-scales of variability. Oke (1967) reported continuum variations of 0.1 mag/d, with a change of colour in the sense that the object becomes redder when fainter. In the infrared, Neugebauer *et al.* (1986) deduce that the continuum emitting region must have a size of less than half a light year, while Impey *et al.* (1982) find variations by a factor of 2 in about one day. In the blue, Barbieri *et al.* (1985) find variations on different time-scales down to 1 d, with significant changes on scales of hours, while the polarized flux and position angle can change drastically in 7.5 hr. Bregman *et al.* (1986) report line and continuum changes in the UV in less than six months and Brown *et al.* (1986) find factor of 2 changes in the X-ray flux within a week. The radio flux also exhibits rapid (6-month) variations (Brown *et al.* 1986; Simon, Johnston & Spencer 1985).

Barbieri *et al.* (1985) find, from an analysis of the power spectrum of the *B*-band light curve, two significant periods of 2130 and 1540 d. More interestingly, Brown *et al.* (1986) find that the optical and near-infrared continua vary together (with a lag of less than a few weeks), while the scant UV data implies that UV and optical vary together with a lag of the order of months or less. They also find that, in general, the spectrum is flat when the object is bright and steepens when it fades (also observed in BL Lacs, as reported by Moles *et al.* 1985); although there are observations which do not fit this pattern, the extreme high and low states certainly comply, as can be seen from the continuum energy distributions collected by Kidger & Beckman (1987; see also Bregman 1986).

Unfortunately, there is an almost complete absence of published emission line data. A large number of spectra seem to have been collected by Stephens & Miller (1984), but they have not yet published them in the refereed literature and report little information on what seems to be very interesting data. Stephens & Miller find that the C III] equivalent width remains approximately constant while the fluxes of the lines and continuum vary; also C IV does not seem to vary as much as C III]. They are able to put an upper limit to the lag in the response of the C III] to continuum variations of 1 month. This limit is not inconsistent with the apparent 3-d change we discuss above. The value quoted by van Groningen & de Bruyn (1988) for the C III] flux in 1982 is 3.5×10^{-15} erg cm^{-2} s^{-1}, although the object was several magnitudes brighter at the time, while that given by Miller & French (1978) for the epoch 1968–77 is a factor of 4 larger.

Two explanations have been put forward to account for the rapid variations in 3C446. First, as a radio source it shows superluminal brightening of spatially fixed components (Porcas 1985), although it is also a strong candidate for superluminal motion (Simon, Johnston & Spencer 1985). Bregman *et al.* (1986) conclude, by comparing the Lα to continuum ratio to that of normal quasars (Kinney *et al.* 1985), that the ultraviolet radiation is weakly beamed, if at all. Using IR data, Courvoisier, Bell-Burnell & Blècha (1986) conclude from rapid variations with no change in slope that radiation in this band has a beamed component. A second argument, that has been put forward to explain the relatively rapid changes seen in Lα by Bregman *et al.* (1986), is that the emitting gas is confined to a small region, in linear and angular size, located close to the line-of-sight to the observer. We return to this point in Section 3.

2.3 Pks 2344 + 09

We do not see large changes in the total flux of Mg II, although the variations of the core component are somewhat larger (20 per cent, Table 3). Grandi (1981) gives a Mg II flux of 6.9×10^{-14} erg cm^{-2} s^{-1} after correction for special relativistic effects to the rest frame, i.e. multiplication by $1+z$. The nature of these changes in the narrower component is interesting and clearly affects the shape of the profile (a similar effect happens in Pks 2134 + 004). Fig. 5 shows the nature of the changes. Note that a central absorption component is a possible cause. Absorption features are clear in the blue wing of the August 1984 spectrum, confirming results from an *IUE* spectrum which also shows self-absorption in the blue wings of C IV and Lα. The changes, as seen in Fig. 5, could (as discussed above) be due to a resolved extended component. We have carefully checked that there is no sign of extended emission in the 2D frames and this explanation can be thus discarded. Note that the broad Mg II component which forms the base of the line has also changed in 2344 + 09 as can be best seen in fig. 6(b) of Paper I, between 1984 August and 1986 July. A spectrum is also shown by Grandi, but its lower resolution does not allow us to say anything about the Mg II profile. Finally, in the 1984 August spectrum, the C II] λ2326 line is clearly present but there is no sign of it in the spectrum taken in 1985 June, so it is likely that this line has also varied.

Table 3. Fluxes and equivalent widths for Mg II in Pks 2344 + 09. Fluxes are in units of 10^{-14} erg cm^{-2} s^{-1}. Measuring intervals are (observed wavelengths): 4645 < core < 4720 Å, 4505 < total < 4832 Å.

date	core	total
4.8.84	1.9/14.3	7.0/65
13.6.85	1.7/13.8	6.3/60.8
31.7.86	2.4/18.1	7.2/65.5

2.4 3C345

The six spectra we have obtained of this object are shown in fig. 8(b) of Paper I. The continuum was bluer in 1984 August and flat in the other epochs. From this figure it looks as if the Mg II profile might have changed. Fig. 6 presents a closer look at these profiles, with the 1985 June spectrum (dotted line) superposed on other data. From this figure it is clear that the line was different in 1985 October and 1986 July, when it was more peaked with an opposite change seen in 1985 March. Changes in the flux of the line are also noticeable, with a maximum amplitude of 61 per cent between 1984 August and 1986 July. Fluxes and equivalent widths for Mg II are presented in Table 4, along with fluxes for three continuum windows.

Netzer *et al.* (1979) have studied the spectral variability of 3C345 (see references therein for an account of previously published data). In their fig. 1(b) they summarize their data by plotting Mg II intensity and equivalent width and the *B* magnitude versus the date. They conclude that the emission line changes (seen only in flux and not in the profile because of their lower

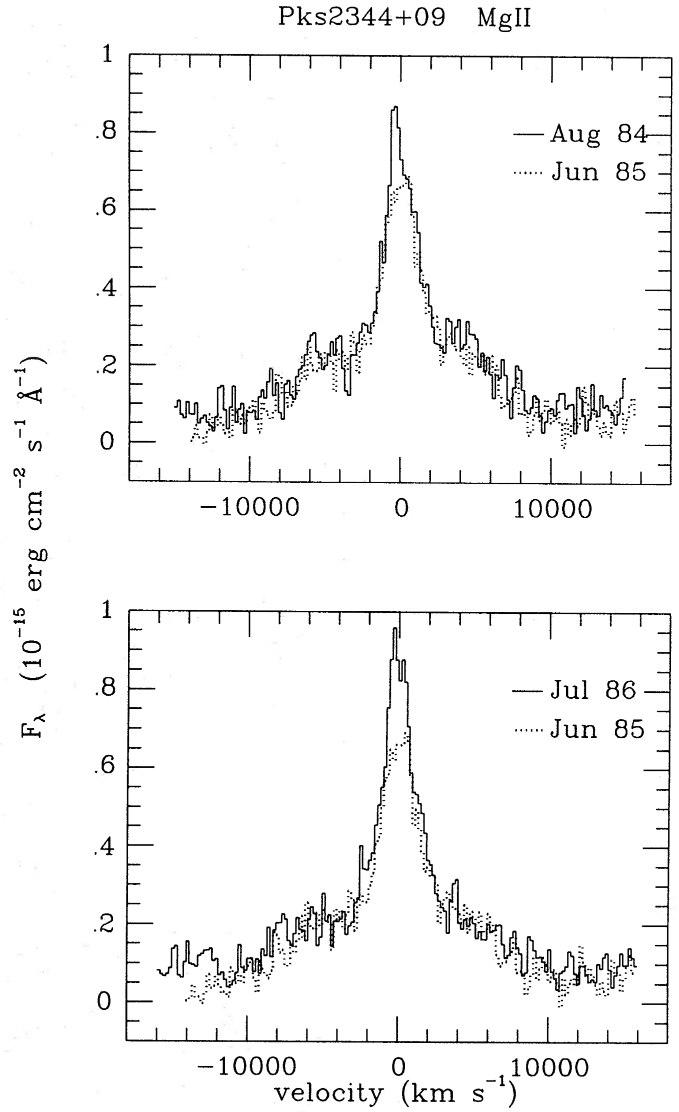


Figure 5. Comparison of the Mg II profiles in Pks 2344 + 09 during 1984 August and 1985 June (top) and 1985 June and 1986 July (bottom). For this comparison the continuum under the three spectra has been subtracted, so that the ordinate axis scale is only relative. The central observed wavelength for the velocity origin used is 4679.4 Å. Note how the changes are restricted to the line core.

Table 4. Fluxes and equivalent widths for Mg II and continuum in 3C345. Fluxes are in units of 10^{-15} erg cm^{-2} s^{-1} for Mg II and 10^{-15} erg cm^{-2} s^{-1} Å^{-1} for the continuum. Measuring intervals are (observed wavelengths): $4325 < \mathrm{Mg\,II} < 4590$ Å, and $3780 < 3810 < 3830$ Å, $4825 < 4865 < 4905$ Å, $5920 < 5950 < 5980$ Å for the three continuum windows.

date	MgII	continuum		
		3810	4865	5950
2.8.84	68.8/37.4	2.8	1.6	1.4
8.3.85	91.8/84.3	1.4	1.0	0.8
13.6.85	81.6/68.8	1.4	1.1	0.9
8.10.85	99.2/65.7	1.5	1.2	1.0
5.6.86	84.2/77.3	1.2	0.9	0.9
30.7.86	110.6/73.4	1.7	1.4	1.1

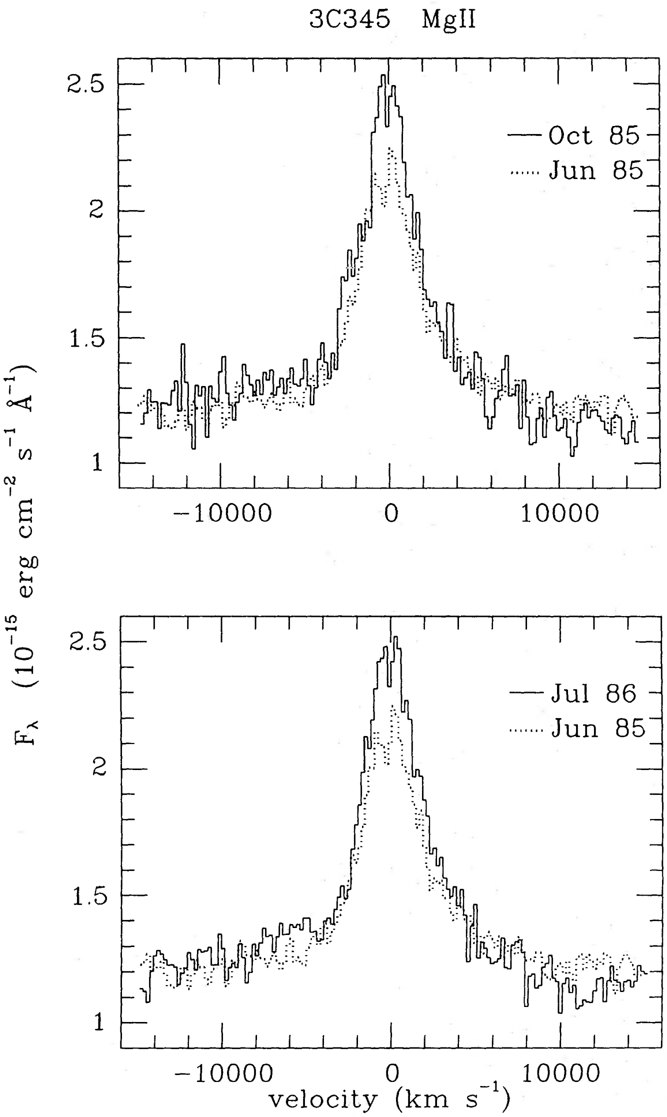


Figure 6. Comparison of the Mg II profiles in 3C345 during 1985 June and October (top) and 1985 June and 1986 July (bottom). The 1985 October and 1986 July data have been shifted down by subtracting a constant of 0.3 and 0.35 ordinate units, respectively. The central observed wavelength is 4463.0 Å. Note again that changes are most prominent in the line core.

resolution) are not significant and thus that the BLR should be large enough that the line flux does not respond to continuum changes. By comparing their data (measured from their fig. 1b) with ours we get the following results. The average value of Mg II flux (same units as Table 4) from Netzer *et al.* is 95.8 ± 19 (1σ from the mean) with the largest difference between two of the values being of 35 per cent. From our data the average is not significantly different, 89.4 ± 13.3, with the largest difference at an individual epoch being 24 per cent. Thus it appears that although the average flux has remained on the same level (92.3), the individual excursions are significantly different (a factor of 1.75) and indicate that the line is changing.

These changes may be in response to those in some of the continuum components identified by Babadzhanyants & Belokon' (1984, 1986). These authors make a study of the relationship between the optical light curve and the radio data (light curve and motion of the VLBI superluminal components). They show how the onset of the slow optical bursts (type two, with 1 yr time-scale) coincide with the zero separation of the VLBI components from the nucleus, thus

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finding an intriguing correlation between the optical slow bursts and radio blobs. They also show how the radio light curve closely follows the optical light curve with a delay of the order of several months (independently suggested by Lloyd 1984).

A final remark about the Mg II changes in response to the continuum is in order. The different continuum components identified by Babadzhanyants & Belokon' are very interesting [we can think in a similar way of 3C345, 3C273 (Angione & Smith 1985), BL Lac (Kidger, private communication) and other objects with good light curves]. The point is that, as is often argued in discussions on the subject, the gas responsible for the line emission does not have to view the same continuum that we see. For example, in the case of 3C345 if the gas is responding to the 10-d continuum changes (of less than 1 mag) then these are too fast and on average the ionization level is not going to change very much, because several pulses of ionizing and non-ionizing continuum are affecting the BLR at the same time. On the other hand the third, slowest component has only risen by about 0.5 mag or less since the time of the Netzer *et al.* observations and this change might not be enough to change the BLR ionization and/or might not be affecting the ionizing flux. More promising are the slow changes with a time-scale of 1 yr and a change in flux of 1 mag. We note that the data of Netzer *et al.* were taken at the end of the 1977 s-burst, which unfortunately was only a faint one (less than 0.5 mag brighter at peak). To test whether this latter type of burst in 3C345 affects the BLR, spectroscopy would be needed during the epochs 1967–69, 1971–74 and 1982–87. We have not found published spectra taken at these dates, but we are continuing our study and are waiting for the response of the Mg II line to the last slow burst (1980–87).

3 Discussion

The first result which follows from the previous section is that indeed the HLAGN do show variability, not only in their continuum, as was previously established, but also in the emission lines. The observed variations in the emission lines show features which had not been foreseen from theoretical considerations.

First, we see that the nature of the line variability is similar to the case of lower luminosity AGN (LLAGN), in that they affect not only the line fluxes (for a clear case see Fig. 4) but also the profiles (Fig. 3). An unexpected point about the profile changes, however, is that, systematically for several objects, these changes affect only the core of the line. We have examples of this effect for Mg II in Pks 2344+09 and 3C345 (Figs 5 and 6) and Lα in Pks 2134+004. This type of behaviour has not been reported for low-luminosity objects, in which the variations mostly affect the broad wings of the lines. The variations of the core prevent us from identifying the narrower of the two components seen in the lines with emission from the classical narrow line region (NLR); simply using the well-known argument of the expected time-scale of variations for emission coming from a much larger NLR. Also, the width of this core component is $\sim 2000\ \mathrm{km\ s^{-1}}$ (Figs 5 and 6) and is larger by a factor of 2 than the width of a line from the NLR. In 3C390.3 the variable 'narrow' C IV component is also much wider than the optical lines from the NLR (Clavel & Wamsteker 1987). Such a result is confirmed by similar behaviour reported from *IUE* data for other HLAGN (Gondhaleker *et al.* 1987).

There are several possible explanations to account for such variations. First, they could be due to a variable self-absorbed component; this might explain the variations affecting mainly the line core, where the optical depth is larger. This could occur, for example, if clouds with a large optical depth cross the line-of-sight to the observer; these clouds would also have (in Keplerian kinematics) a very small velocity component, and thus contribute mainly to the emission line core. Ferland & Rees (1988) have developed some photo-ionization models with high densities which are relevant in this connection. Secondly, these variations can be explained with an emission line region in which cloud kinematics are dominated by an outwardly accelerating flow, e.g. radiation pressure, in which case those clouds nearer to the continuum source would have a smaller velocity, and thus the variations in the line produced by changes in the ionizing continuum would develop from the line core outwards to the wings, in a symmetric fashion. This is compatible with changes seen in 3C345 but not in 2344+09. Thirdly, these variations can be brought about by occultation or structural changes in a disc-like emitting region, similar to those shown in fig. 6(b) of Hellier *et al.* 1987.

Turning to consider the time-scale of the observed variations. We noted in the introduction to Paper I that the expected time-scale for line variability in HLAGN was typically larger by about an order of magnitude than that of LLAGN. Thus if we see few significant line changes on time-scales shorter than two to three weeks in LLAGN then we would expect similar changes only after about a year for a HLAGN. Nonetheless, important changes (larger than 50 per cent) in the emission lines are observed in less than two months (see entries 4 and 5 in Table 1 and entries 5 and 6 in Table 2). Our data indicate that the scaling expected for the size of the BLR in HLAGN from that of LLAGN is incorrect. This scaling derives from the results of photo-ionization models: a crude version of this is given in Table 5 below, assuming constant density $n_e = 10^{10}$ cm^{-3} in all objects. The values of U have been obtained from fig. 1 of Mushotzsky & Ferland (1983) according to the appropriate line ratios for the objects. These values may be compared with sizes deduced from the observed rate of change of line intensity using, for definiteness, Terrell's (1967) formula. Note that this sets a limit on the size of an emitting region, assumed spherical. We also stress that our data are not capable of measuring a size by determining the *lag* between continuum and line: much more regular monitoring is needed to achieve that goal.

Because our results undermine current theories, we have checked carefully each case of rapid variation that showed up in our programme. Overall, however, we have become convinced of the reality of the pattern of rapid variations and are strengthened in this belief by

Table 5. Sizes of line emitting regions as deduced from the variations observed in four emission lines, Lα, C IV, C III] and Mg II using Terrell's (1967) formula 12 and as predicted from standard photo-ionization models. The two epochs chosen in every case are those for which the largest relative change occurred and are closest in time. The size from the standard photo-ionization model is obtained from the definition of the photo-ionization parameter, $U = (Q/4\pi r^2 c n_e)$, where we have used $\log U = -2.3$ for 3C446 and -2.5 for Pks 2134+004, Pks 2344+09, 3C345, 3C454.3 and 3C232 as deduced from fig. 1 of Mushotzsky & Ferland (1983). The values of Q (in units of 10^{55} s^{-1}) are represented in column 6, as obtained from the overall energy distributions shown in Brown *et al.* 1986 and Kidger & Beckman 1987. Note how the discrepancy between the two methods is typically larger than one order of magnitude.

				Terrell		photoionization	
object	line	T(days)	$\frac{\Delta L}{L}$(%)	D(days)	Q(10^{55})	D(days)	discrepancy[1]
3C446	CIV	54	57	50	49	1970	1.6
	CIII]	54	75	38			1.7
2134+004	Lα	54	40	59	52.3	2550	1.6
	CIV	54	36	65			1.6
	CIII]	54	59	40			1.8
2344+09	MgII	313	11	2258	11	1172	-0.3
3C232	MgII	454	25	1528	4.7	767	-0.3
3C454.3	MgII	55	25	150	25.7	1791	1.1
3C345	MgII	55	27	161	8.9	1055	0.8

[1] Discrepancy in orders of magnitude.

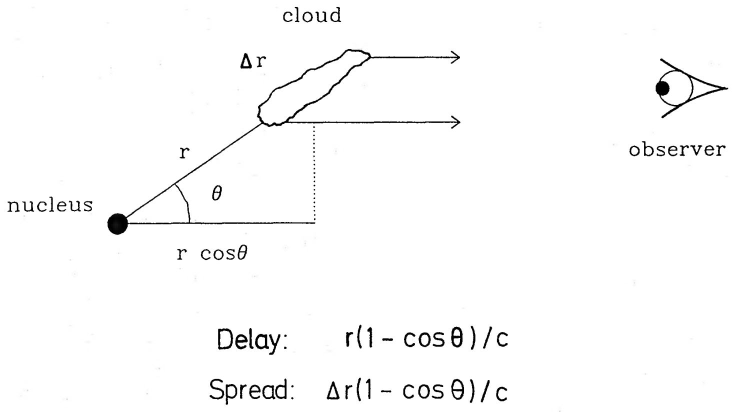

Figure 7. Schematics of the BLR line-of-sight effect (see Section 3).

similar results obtained by others (Stephens & Miller 1984; Bregman *et al.* 1986; Gondhalekar *et al.* 1987). We thus conclude that the sizes we find are in conflict with those expected from photo-ionization models and that this discrepancy is in need of an explanation in terms of the physics of the source rather than of observational technique.

Earlier we alluded to the possibility that anisotropies in the BLR might help account for these discrepancies. Two variants of this idea have already been discussed. First, Netzer (1987b) has pointed out that if the BLR is disc-like then smaller lags may be expected; secondly, Bregman *et al.* (1986) accounted for their results on 3C446 by proposing a BLR confined close to the line-of-sight to the continuum source in this object. On the other hand, Ferland & Rees (1988) have been looking for a solution in terms of increasing n_e to (say) $10^{14}\ \mathrm{cm}^{-3}$ in the BLR (or in part of the BLR since C III] is formed at $n_e \leq 10^{9.5}\ \mathrm{cm}^{-3}$) so that the same ionization parameter corresponds to a smaller distance from the nucleus and hence shorter lags.

We prefer a solution of the type proposed by Bregman *et al.* in terms of anisotropic geometries (see Fig. 7) which does not disturb the general agreement[★] between the line ratios predicted by the models and those found in the data. If we take the results of Table 5 to indicate that the sizes indicated by lags are smaller than the sizes indicated by photo-ionization models by more than about a factor of 10, then we are proposing that the BLR clouds lie an average angle θ off the line-of-sight where (see Fig. 7) $1-\cos\theta \geq 0.1$. This corresponds to $\theta \leq 26°$.

Now of course in individual objects such a conspiracy is possible and requires no further comment (e.g. Bregman *et al.* 1986). However, we are now finding this effect routinely at least in OVV quasars and further discussion is necessary. For if the radiation field from AGN is isotropic, we would expect only 5 per cent of cases to be lined up with the required precision (or 10 per cent if the BLR are two-sided cones with the back side obscured) by chance alone.

There is now, however, significant evidence that the optical and UV continuum emission from AGN is anisotropic; this includes:

(i) The success of beaming models (Orr & Browne 1982; Wills & Browne 1986).

(ii) The existence of accretion discs (Malkan & Sargent 1982; Netzer 1987b; Pérez *et al.* 1988a).

[★] However, we note that this agreement is in part due to the many free parameters in the photo-ionization models as compared with the number of observables – the intensities of the emission lines observed. In particular, the values of U, n_e and the abundances, on which the models heavily rely, are only poorly constrained from the observations, as Netzer (1987a) and others have made clear. For a recent review of the variability in AGN and the problems with the standard model see Peterson (1988).

(iii) The hidden Seyfert 1 nucleus of NGC1068 (Antonucci & Miller 1985).

(iv) Anisotropy of the photo-ionizing illumination of the Extended Narrow Line Region (Unger *et al.* 1987).

(v) 'Too rapid' line variations (Stephens & Miller 1984; Bregman *et al.* 1986; Gondhalekar *et al.* 1987; this paper).

In particular, recently Browne & Murphy (1987) have shown that AGN with R, the ratio of compact radio flux, in excess of unity (which in the context of the Orr & Browne unified scheme are beamed within $\sim 25°$ of the line-of-sight) are a factor of about 10 brighter in the optical and X-rays than those with $R < 1$ for the same extended radio power (supposed to be isotropically emitted). While the Browne & Murphy result only applies to radio-emitting AGN, one would still suspect that this implies powerful selection effects in any samples involving any optical (and hence UV) or X-ray selection in favour of objects which are beamed in our direction.

If the optical and UV continuum is significantly beamed, then it is natural that the BLR itself should be anisotropic and, if selection effects favour finding sources beamed towards us, it is natural that all the BLRs should 'point' in our direction. Further calculations and simulations are now necessary to see if the degree of anisotropy suggested by Browne & Murphy accounts for the (still poor) statistics of rapid line variability in a quantitative way.

Our conclusion at this point therefore is that the results of this paper and other sources cited which find unexpectedly rapid line variability are consistent with anisotropic continuum emission and provide further evidence in favour of it.

4 Future developments

The approach to be followed, if we want to find tight constraints to the models for the kinematics of the BLR, was already clearly stated by Blandford & McKee (1982). The inherent handicap for the study of AGN (as opposed to similar stellar systems involving accretion discs) was explicitly mentioned by Penston (1986). He applies scaling laws to the time-scale and wavelength to see the correspondence between the data for binaries and that for AGN and finds that 18-yr data in the light curve at 4000 Å for a $10^8\ M_\odot$ nucleus corresponds to 6 s at 0.2 keV for one solar mass. Great persistence and patience are necessary to study AGN light curves! Blandford & McKee estimate that, for a typical bright Seyfert, bi-weekly observations for a period of 2 yr would be satisfactory. Such a programme is being carried out to study the Seyfert I galaxy NGC 5548 with *IUE*. This programme would imply, if we were to study a small sample of objects, a dedicated medium-sized telescope.

There is an alternative programme which would improve the present one and is not as taxing on resources as the above outlined ideal. This programme would monitor photometrically a small sample of objects on a weekly basis with the sparse spectrophotometric monitoring about thrice a year. The photometry could be reduced as soon as data is collected and if an object is seen to vary significantly then a closer spectroscopic monitoring (a spectrum every 3 or 4 d) could be started, to map the response of the BLR to the continuum change. This would provide the necessary data to study the object in the active phase, which is when more information can be obtained from the spectra. This is less demanding of telescope time but requires adjustments to the present managerial procedures for assigning and scheduling telescopes.

We hope to have conveyed to the reader the importance and feasibility of the spectrophotometric monitoring of HLAGN and encourage astronomers in the field to combine efforts, in a collaborative quest to unravel the nature, geometry, kinematics and physical conditions reigning in the centres of high and low luminosity active galactic nuclei.

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